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TRANS-ATLANTIC FLIGHT FROM THE METEOROLOGIST'S POINT OF VIEW.

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INTRODUCTION.

The marvelous development of aviation finds no better illustration than the fact that, within 15 years of the time when flying in heavier-than-air machines was proved to be practicable, trans-Atlantic flight has become one of the leading topics in the daily press and is receiving the earnest attention of many of our most ambitious aviators. During the past few months plans for the realization of this ambition have more and more assumed a definite, concrete form, and there is every reason to believe that, within a short time, trans-Atlantic flight will have become an accomplished fact. Much has been written on this subject in the various aviation and other periodicals, but these discussions have for the most part dealt with the mechanical problems involved, including engine performance, endurance, fuel capacity, etc. Comparatively little has been written relative to the meteorological aspects of the project, although there are some exceptions, specific reference to which will be made later. It is true that improvements in aircraft may eventually result in making them less dependent upon weather conditions than at present, but it is not likely that the time will ever come when a knowledge of atmospheric conditions and changes can not be used to advantage by the aviator. Certainly at the present time, with the limited cruising radius of even the highest powered machines, weather conditions along a course as great as any of those that may be selected for crossing the Atlantic should be known as accurately as possible, in order that the aviator may know beforehand his "margin of safety" and may make his plans accordingly. The purpose of this paper is, therefore, briefly to present (1) a statement giving the present state of our knowledge relative to average surface meteorological conditions over the North Atlantic; (2) a similar statement as to free-air conditions; and (3) an analysis showing the assistance that may be rendered by the winds, providing an aviator, with this in mind, carefully selects his time for flight.

Before taking up these points in detail a few words should be said as to possible routes. Those most frequently proposed for the trip from America to Europe and return are (a) Newfoundland to Ireland and (b) Newfoundland to the Azores, thence to Portugal. Another suggested route is from Labrador to Scotland, via Greenland and Iceland. The only advantage of this route over the others is the shorter distance between successive landing points. Among its disadvantages are: Lower temperatures than over the routes farther south; difficulty

of providing suitable landing places in Greenland and Iceland and of finding them even if they could be established; greater probability of cloudiness and of opposing winds, since this route lies to the north of the region of greatest storm frequency; difficulty, if not impossibility, of securing meteorological data at the time of flight; and remoteness from steamship routes and, therefore, improbability of rescue in case of accident (cf. 30). Inasmuch as airplanes of sufficient power and capacity have been developed for flying a distance at least as great as that from Newfoundland to the Azores the extreme northern route will be given no further consideration.

For the return trip from Europe to America there have been proposed, in addition to the two already mentioned, a route from Portugal to northern Brazil, Guiana, or Venezuela (1); and one from Portugal to the Lesser Antilles (2). In these instances, however, the flights contemplated were to be made by means of relatively slow-traveling airships or dirigible balloons. For the eastward journey they were to go direct from Newfoundland to Ireland, thus adding to the inherent speed of the airship the assistance furnished by the prevailing westerlies. In returning, however, the wind resistance offered would be so great as to make the journey hazardous and on a large percentage of days impossible. The southern routes would not only avoid these head winds, but would lie for the most part in the region of the northeast trades. In spite of their greater distances, therefore, these southern routes offered decided advantages for airships or dirigible balloons. In the case of high-speed airplanes, on the other hand, the assistance furnished by the trade winds would be offset in large part, if not altogether, by the greater distance to be traveled. On properly selected days the less favorable winds along the routes farther north would be more than compensated for by the shorter distances. The several routes together with approximate distances are shown in figure 1, but in the present paper attention will be given only to those between Newfoundland and Ireland and between Newfoundland and Portugal via the Azores.

1. AVERAGE SURFACE WEATHER CONDITIONS OVER THE NORTH ATLANTIC.

References (3) (4) (5) (6).

Temperatures.—Temperatures are of interest chiefly in connection with their effect upon the aviators and upon engine performance. In Table 1 are given average monthly and annual values at four selected places.

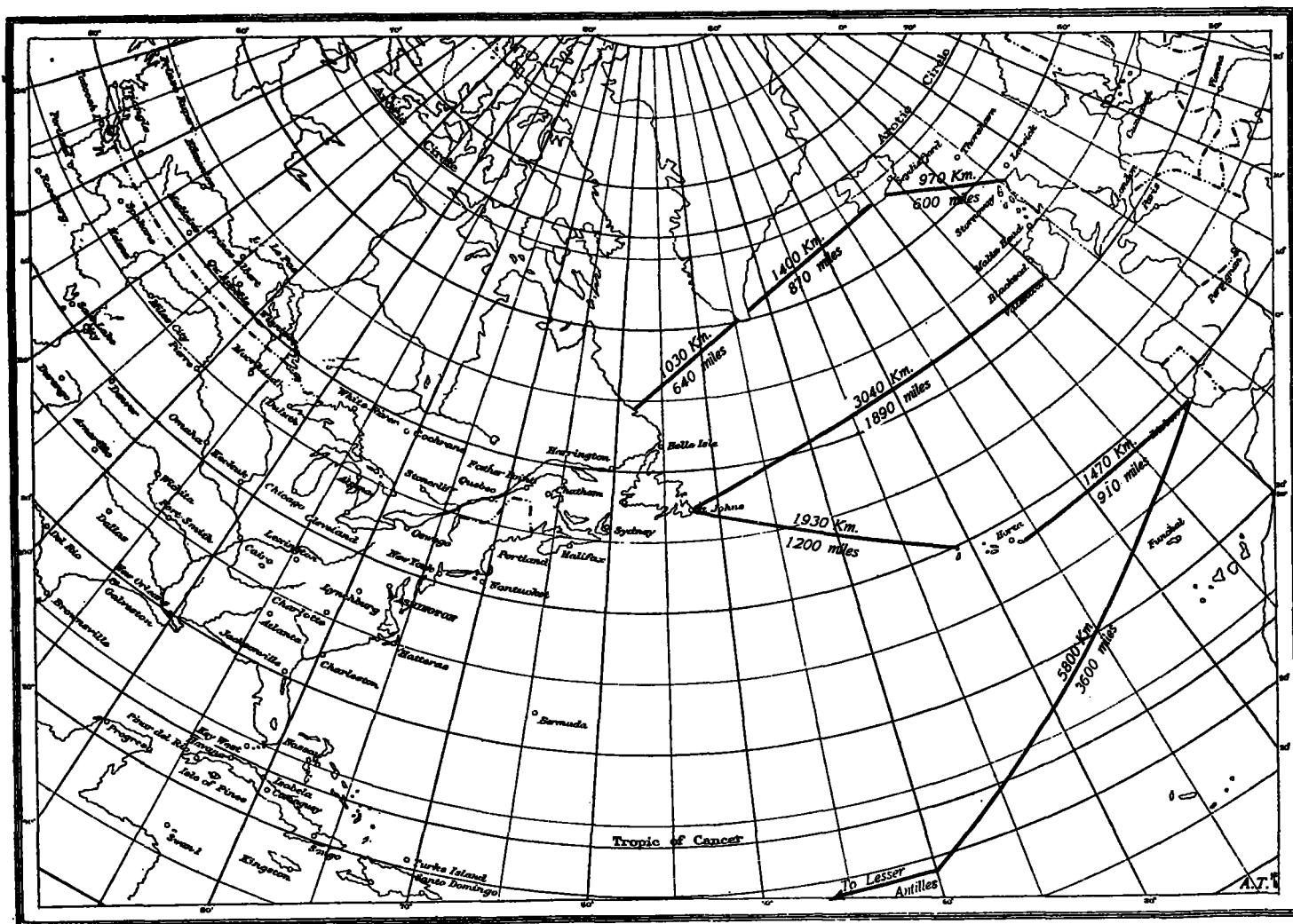


FIG. 1.—Different routes that have been proposed for trans-Atlantic flight. (Distances in kilometers and statute miles along great circles.)

TABLE 1.—Mean monthly and annual temperatures, °C., at St. Johns, Newfoundland; Valentia, Ireland; the Azores; and Lisbon, Portugal.

	St. Johns.	Valentia.	Azores.	Lisbon.
January.....	- 5	7	14	10
February.....	- 5	7	14	11
March.....	- 2	9	16	12
April.....	2	11	17	14
May.....	6	14	19	16
June.....	11	15	21	19
July.....	15	15	22	21
August.....	16	15	21	21
September.....	12	14	21	20
October.....	7	11	17	16
November.....	3	9	15	13
December.....	- 2	7	15	10
Annual.....	5	10	18	15

Annual and diurnal ranges, as well as those due to abrupt changes in weather, are greatest in Newfoundland and least in the Azores. Minimum temperatures as low as -25°C . have been observed at St. Johns and as low as -5°C . at Valentia. Freezing temperatures have never been reported in the Azores or at Lisbon. Extreme maxima do not differ greatly at the four places, Lisbon showing the highest, 35°C ., and Valentia the lowest, 27°C . Over the ocean the horizontal temperature gradient is fairly steep in winter from Newfoundland to longitude 40°W . along both routes, and practically zero from that longitude to Ireland and Portugal. During the summer there is a slight rise from Newfound-

land to longitude 45°W . over the Azores route; along the remainder of this course and along the entire course from Newfoundland to Ireland there is practically no change.

Relative humidity.—Comparatively little has been done in a critical way in the study of humidity conditions over the oceans. Among the most interesting observations are those on the British steamship *Scotia* (7) and on the U. S. Coast Guard cutter *Seneca* (8). These observations were made in the late spring and early summer months and showed in practically all cases a relative humidity above 80 per cent. A large number of observations in December, as computed by the marine section of the Weather Bureau, gave an average value of 86 per cent. There seems to be little, if any, variation with the seasons, but there is a small variation with latitude, values at latitude 60°N . averaging about 90 per cent, as against 85 per cent at latitudes 40° to 50°N .

Cloudiness.—The average cloudiness along the northern route is about 70 per cent throughout the year. This statement is somewhat misleading, so far as aviation is concerned, inasmuch as fogs are included with clouds in arriving at this result and, as will be shown later, these fogs extend to low altitudes only and the aviator would, therefore, oftentimes have a clear sky above him, whereas at the earth's surface 100 per cent cloudiness would be recorded. It is probable that in summer the average cloudiness above the fog level is

about 50 to 60 per cent. Between Newfoundland and the Azores it varies from 65 per cent in winter to 55 per cent in summer, and between the Azores and Portugal, from 55 to 45 per cent.

Precipitation.—Very little is known as to the amount of precipitation over the North Atlantic Ocean. Data are available, however, for the adjoining coasts and these indicate an annual amount of about 140 cm. in Newfoundland; 100 on the west coast of Ireland and in the Azores; and about 70 in southern Portugal. According to Supan (4) the average is about 200 cm. over the greater portion of the Newfoundland-Ireland route, and over part of the region between Newfoundland and the Azores; from the latter to Portugal the mean value is probably about 100 cm. Precipitation normally occurs on about 160 days in Newfoundland; 200 in Ireland; 170 at the Azores; and 100 in Portugal. Over the ocean it probably occurs on about 200 to 250 days along the northern route and on about 150 to 200 days along the southern route. In all regions precipitation is greatest in amount and frequency in winter and least in summer.

Fog.—One of the most serious obstacles to trans-Atlantic flight appears to be the large percentage of days on which fog occurs, particularly near the American coast. This amounts in the regions southeast and east of Newfoundland to about 60 per cent in summer and about 20 to 35 per cent in winter, the frequency in the latter season being greatest to the southeast. Near the Irish coast it varies from about 10 per cent in summer to 5 per cent in winter. Fogs rarely occur near the Azores or between them and Portugal. In general the Newfoundland fogs occur as the result of warm moisture-laden winds blowing from the Gulf Stream regions over the colder waters of the Labrador Current. Another and, according to Capt. Campbell Hepworth, the commonest kind of fog encountered in this part of the Atlantic is a calm-weather fog of small vertical extent in which the sea is slightly warmer than the air. In discussing this phenomenon Taylor (7) concludes "either that when a fog blows over warmer water there is no appreciable tendency to dissipate it or that, under certain circumstances, warm water under cold air tends to produce a fog in some other way than that with which we are familiar and that this effect balances the tendency of warm water to dissipate a fog produced by cooling." Probably such fogs are of a temporary nature, having already been formed under the usual conditions, but later blown over water with a higher temperature than their own. They occur only during calm weather and quickly disperse as soon as a breeze sets in.

Pressure.—Pressure distribution over the North Atlantic may be briefly described as consisting essentially of a belt of high pressure, known as the "Horse Latitudes" at about latitudes 30° to 35° N., with a semipermanent HIGH near the Azores; and a belt of low pressure at about latitude 60° N. with lowest values in the vicinity of Iceland. Because of the relative warmth of the ocean and the adjacent continental areas during the different seasons, the Azores HIGH is best developed in summer and the Iceland LOW in winter. The seasonal difference is greatest in the case of the Iceland LOW, the final result being that the northward pressure gradient is strong in winter, but relatively weak in summer. The isobars, in general, run more or less parallel to the lines of latitude from Newfoundland to about longitude 20° W. at all seasons. Farther east along the Ireland route they continue eastward in summer, but turn to east-northeast and northeast in winter, under the influence of the Iceland LOW. From the Azores to Portugal they turn south-

ward in summer around the Azores HIGH, but are nearly west to east during the winter.

Wind.—As a result of the pressure distribution, thus briefly outlined, winds in summer are from a west-southwesterly direction, with a mean velocity of 8 m. p. s., at all points along the northern route; in winter they are westerly, with a slight north component, i. e., a component from the north, mean velocity about 10 m. p. s., from Newfoundland to longitude 45° W. Farther east they have a strong south component, becoming southwesterly near the British Isles. The mean velocity along this section of the course is 10 to 15 m. p. s., being highest between longitudes 45° and 20° W. Over the southern course winds in summer are southwesterly, 8 m. p. s., to longitude 40° W.; variable and light thence to the Azores; and northerly, 8 m. p. s., between the Azores and Portugal. In winter they are west-northwesterly, 10 m. p. s., to longitude 40° W.; westerly, 10 to 12 m. p. s., thence to the Azores; and west-southwesterly, 10 m. p. s., between the Azores and Portugal. The percentage of winds from a westerly direction, i. e., between north-northwest and south-southwest, varies along the northern route from about 85 in winter to 70 in summer; near the Azores, from 75 to 65; and from the Azores to Portugal, 40 to 30. In the last-named region winds from all directions are about equally frequent in winter, but in summer northerly winds predominate.

Gales.—Practically all of the cyclonic disturbances that move across the United States, no matter what their place of origin, enter the North Atlantic Ocean slightly to the south of Newfoundland, moving thence east-northeastward toward the Iceland LOW, and thus crossing the northern route roughly between longitudes 30° and 40° W. These storms vary considerably in size, intensity, and rate of travel. In general, they are larger and travel more slowly over the ocean than over the continents. They are, moreover, more frequent, more intense and faster moving in winter than in summer. In their movements across the Atlantic, the more intense cyclones are often accompanied by gales having a velocity of more than 20 m. p. s., the directions of these gales depending upon the part of the storm in which the observations are made. Thus, considering a typical case, viz, a well-developed LOW leaving New England and passing south and eventually east of Newfoundland, we should expect to have at the latter place gales successively from the east, northeast, north, northwest, and west. Along the Ireland route the percentage of days on which such gales occur varies in general from about 25 in winter to 5 in summer. In winter they are often accompanied by violent snow squalls. From Newfoundland to the Azores the percentage frequency of gales is about 20 in winter and 3 in summer; from the Azores to Portugal, about 7 and 1, respectively.

Tropical cyclones.—Tropical cyclones, or hurricanes, occur only in the summer and autumn months, reaching their greatest frequency in August, September, and October. The average number in each year is only about 3 to 5. These storms generally originate in the region between the West Indies and the northern coast of South America, whence they travel slowly northwestward, then northward, to the southeastern coast of the United States. From this region they usually move northeastward along the coast and assume the characteristics of extratropical cyclones. So far as trans-Atlantic flight along the two courses under consideration is concerned, the aviator need therefore feel no more anxiety from hurricanes than from the areas of low pressure that originate in different portions of this country and enter the Atlantic Ocean from the St. Lawrence Valley.

2. AVERAGE FREE-AIR CONDITIONS OVER THE NORTH ATLANTIC.

References (2) (9) (10) (11) (12) (13) (14) (15) (16) (17).

On this subject there is but little information available, so far as actual observations are concerned. The following discussion is, therefore, based for the most part on numerous free-air observations that have been made over the eastern portions of the United States and Canada and in different parts of Europe, and an effort is made to apply these results to the air over the ocean, bearing in mind the relative effects of land and water surfaces on the distribution of the meteorological elements above them.

Temperature.—Individual observations over land surfaces show, in the lower layers of the atmosphere, large variations in temperature gradients, from a strongly inverted condition to nearly (sometimes slightly exceeding) the adiabatic rate. The diurnal phase, so characteristic of surface temperatures, disappears at a low altitude, and at higher levels in clear weather there is usually a reversal, due probably to the greater absorption of terrestrial radiation in those levels at night than during the day. The annual variation is also less in the free air than at the surface, with the result that in winter there is on the average little change in temperature from the surface to a height of about 1 kilometer above it, whereas in summer a decrease of about 6° C. occurs. In general, it may be said that the lower the surface temperatures, as compared with the seasonal normal, the smaller is the rate of decrease with altitude. In other words, during cold waves with clear skies and especially during the early morning hours, inversions almost invariably occur. During cloudy weather, i. e., low clouds, temperatures generally decrease from the surface to the cloud layer and increase slightly for a short distance above it.

In the application of the foregoing statements to the free air above the ocean it is important to recognize certain fundamental differences between land and water surfaces in their absorption and radiation of heat. Water surfaces reflect about 40 per cent of the insolation that reaches them and absorb the remaining 60 per cent. Much of the heat thus absorbed is, however, used in evaporating the water and some of the remainder is distributed both vertically and horizontally by the constant movement of the water and by the penetration of the light rays to lower levels, the result being that the surface and therefore the air in contact with it maintains a relatively constant temperature. Land areas, on the other hand, reflect and transmit very little insolation and there is but little evaporation. The specific heat of land is low and moreover there is no movement, as in the case of water, whereby the heat received can be convectionally distributed either horizontally or vertically. Hence, land areas become strongly heated during insolation and similarly cooled in its absence.

The diurnal variation of temperature at the surface in any one locality at sea is seldom greater than 1° C. In general it is probable that the change is not much larger in the free air above the ocean, except that, in the case of coastal waters, winds blowing offshore would bring their characteristic diurnal variations of temperature with them. As has already been stated there is in winter considerable change in surface temperatures from Newfoundland eastward. This is due partly to the effect of the cold winds blowing off the American continent and partly to the difference in temperature of the Labrador

Current and the Gulf Stream. In the free air this difference largely disappears. Observations on the *Seneca* invariably showed a sharp inversion above the cold Labrador Current and the coastal waters, whereas a temperature decrease of 0.5° to 0.6° C. per 100 meters was found above the Gulf Stream. Summarizing, then, we should expect to find at 1 kilometer above the sea approximately the conditions as set forth in Table 2. The summer months include June, July, August, and September and the winter months, December, January, February, and March. Transitions from one group to the other during spring and autumn are gradual.

TABLE 2.—Probable temperature conditions, °C., at 1 kilometer above sea in different portions of the North Atlantic.

	Near Newfoundland.		Near Ireland.		Between Azores and Portugal.	
	Summer.	Winter.	Summer.	Winter.	Summer.	Winter.
Mean.....	10	0	10	5	15	10
Highest.....	25	10	20	10	25	20
Lowest.....	5	-10	5	-5	10	5

It must be distinctly understood that these figures are merely estimates; they are the nearest to actual conditions that we can get at the present time. Considered with reference to those in Table 1, they indicate that at an altitude of 1 kilometer temperature changes along both routes would be less than at the surface, that rarely would temperatures be much below freezing along any part of either route, and that in summer a trip would be attended by mild and comfortable temperatures throughout. The fogs off the coast of Newfoundland should cause no concern in this respect, for, as will shortly be shown, they are low-lying, and above them temperatures are higher than at the surface.

Humidity.—Over land areas relative humidity generally decreases with altitude during clear weather or when only high clouds of the cirrus type are present. As a rule, it falls to about 50 per cent at an altitude of 1 kilometer, but occasionally as low as 20 per cent. When there are low clouds, the humidity remains high to the upper limits of the cloud layer and decreases rapidly above it. When all conditions of weather are considered, the average decrease with height is not large, amounting to only about 10 per cent from the surface to 1 kilometer above it. It is greatest in winter and least in summer. At altitudes greater than 1 kilometer the relative humidity remains practically constant. Above the ocean, due to the higher humidities at the surface, this decrease is probably larger, amounting on the average to 20 or 30 per cent. The *Scotia* observations showed in some cases exceedingly low values at altitudes of less than a kilometer, even with dense fog at the surface. In general, it is probable that an aviator flying at an altitude of about 1 kilometer would experience along the northern route humidities of 50 to 60 per cent in clear weather or when only high clouds are present and about 80 to 100 per cent in weather with low-lying clouds. Along the southern route somewhat lower humidities than 50 per cent would prevail during clear weather, but with overcast skies they would be about the same as along the northern route.

Height of fog.—There is every reason to believe that in the great majority of cases fogs extend to a low altitude only, above the sea. This is clearly shown in the kite records obtained on the *Scotia* (7) and on the *Seneca* (8). The top of the fog is very definite, and above it the

relative humidity decreases rapidly. The temperature usually increases from the surface to the top of the fog and decreases above it. Out of nine kite records in fog obtained on the *Scotia* only one showed fog extending to a height greater than 300 meters, the average being about 150 meters. The one exception was due to long-continued blowing of warm air over successively colder areas, but, even in this case, the top of the fog was at a height of less than 900 meters. Ten kite flights in fog were made from the deck of the *Seneca*, and the temperature gradients indicate that in only one did the fog extend to a height greater than 250 meters. In the one exception it is impossible to give the exact height of the fog, as no humidity values were obtained; but the temperature record indicated an altitude of about 950 meters. In their studies of fog at sea during this and other cruises on the *Seneca*, Wells and Thurs (18) reached the same conclusion with respect to its height, this conclusion being based upon the fact that there is nearly always a higher temperature at the top of the mast than on the ship's deck and that, if this temperature increase continues to greater heights (and kite records show this to be true), a point must soon be reached at which fog is impossible. Additional testimony from local observers, in support of these conclusions, is contained in a recently printed report of the British civil aerial transport committee. This report was published in England during the latter part of 1918, and is briefly reviewed in this number of the MONTHLY WEATHER REVIEW, p. 80.

Winds.—Observations with kites and balloons in this country and in Europe have brought out the following facts with respect to average free-air wind conditions: Velocities are slightly greater at all altitudes in America than in Europe, but aside from this difference the same general tendencies are shown in both countries, viz, a rapid increase, amounting to very nearly 100 per cent, from the surface to about 500 meters above it; practically constant velocity in summer and a small increase in winter from the 500 to the 1,000 meter levels above the surface; and a steady increase in both seasons, but greater in winter than in summer, from the 1,000-meter level above the surface to greater altitudes. The mean seasonal difference is about 1 m. p. s. at the surface and 2 to 4 m. p. s. at an altitude of 1 kilometer. Moreover, all observations show that the increase in wind velocity from the surface to 500 meters above it is practically the same for all directions of wind, but that at higher levels winds from an easterly direction rapidly diminish in strength, whereas those from a westerly direction gradually increase. The easterly winds usually die out altogether before an altitude of 2,000 meters is reached and at higher levels westerly winds prevail. The shifting from one type to the other is usually, nearly always, clockwise with surface winds from east to south and as a rule counterclockwise with surface northeast to north winds. The amount of the turning is directly related to the angle of deviation of the surface wind direction from that of the prevailing westerlies.

Winds, as is well known, tend to flow at right angles to the direction in which the pressure gradient acts, i. e., parallel to the isobars. Owing, however, to friction and eddies, the direction of motion of the surface wind is nearly always inclined to the isobars. The amount of this inclination is greatest in anticyclonic and least in cyclonic systems, the average value on land surfaces being about 30°. Inasmuch as these disturbing influences largely disappear in the free air, we should expect

the winds invariably to veer with altitude.¹ That there are exceptions to this is due to the unequal vertical distribution of temperature that often obtains in adjacent localities, thus producing in the free air isobaric systems decidedly different from those at the surface. Nevertheless, in general it is found that the winds at an altitude of 1 kilometer follow rather closely the direction of the surface isobars. This means that on the average they veer about 30° from those near the ground. The case is somewhat different over the ocean. Here there is less friction, less convection, and there are no topographic interferences at all comparable with those on land. Hence we should expect to find the winds even at the surface blowing more nearly parallel to the isobars, and an inspection of marine synoptic weather maps indicates that this is true, the average inclination being about 10°. This means that the veering of winds with altitude is about 20° less over ocean than over land surfaces. In a similar manner velocities are affected, with the result that they are higher on the sea than on land, that is, they more nearly approach true gradient velocities. It has already been stated that observations show above land an increase of about 100 per cent in velocity within the first 500 to 1,000 meters. Now, surface winds at sea are nearly twice as strong as those on land. Hence the increase with altitude over the sea is much less than over the land. In other words, a trans-Atlantic aviator would not need to fly as high as would a trans-continental aviator in order to derive the greatest possible assistance from the winds; and, conversely, in the case of opposing winds there would be less advantage in flying at a low altitude over the ocean than over the land. Whatever the wind direction, whether favorable or unfavorable, flying at low levels above the sea would be less dangerous than at similar levels above the land, because the air there is less turbulent or "bumpy," as it is sometimes called.

In the foregoing discussion an attempt has been made to present in brief form a general review of average conditions both at the surface and in the free air. A knowledge of these is of interest and importance to an aviator, but should be used with caution, for average conditions seldom occur and they would scarcely ever prevail at all points along a route as great as that from America to Europe. We now come, therefore, to the third part of the paper, namely:

3. THE ASSISTANCE THAT MAY BE RENDERED BY THE WINDS, PROVIDING AN AVIATOR, WITH THIS IN MIND, CAREFULLY SELECTS HIS TIME FOR FLIGHT.

In order to determine, under given conditions of wind, the direction toward which an airplane should be headed in order that it may keep to any desired course, and the resultant speed along that course, it is only necessary to resort to that elementary principle of mechanics, applicable to any body moving through a medium which itself is in motion, viz, the principle of the composition of speeds. For example, in figure 2 let *OB* represent a course which an aviator desires to follow, and *OA* or *S_w* the speed of the wind, this wind making an angle α with the line *OB*.

¹ This veering with altitude is at times visible in the way in which the smoke from steamers spreads. F. J. W. Whipple, in a note on "Wind structures at sea" (M. O. Circ. 26, July 22, 1918), says, "The difference in the bearing of the upper and lower parts of the smoke cloud [from my steamer] was about 5° [in about 50 ft. difference of elevation]. There was no opportunity to estimate the corresponding angle between the upper and lower wind."

Also, let S_a represent the air speed (i. e., speed in still air) of the airplane.

Then the angle β which the airplane should make with OB, in order that the latter shall be the resultant course, may be readily computed, since the sines of the two angles are inversely proportional to the two speeds, or

$$\sin \beta = \frac{S_w \sin \alpha}{S_a}.$$

Also, by completing the parallelogram, we find graphically the resultant speed, or $S_r = S_w \cos \alpha + S_a \cos \beta$.

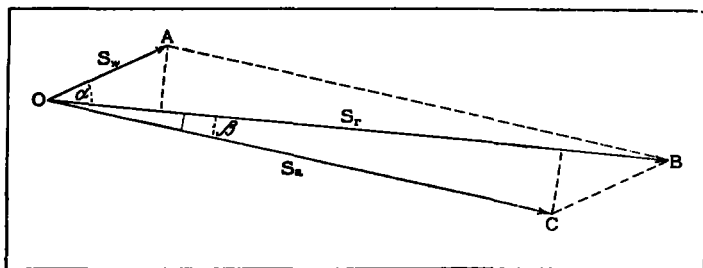


FIG. 2.—Diagram showing resultant course and speed of an airplane under the combined action of its own direction and speed and those of the wind.

To take a typical case, suppose the desired course is E. 5° S.; wind bearing and speed are E. 25° N., 10 m. p. s. (about 22 mi. p. h.); and the air speed of the machine is 40 m. p. s. (about 90 mi. p. h.). Then $\alpha = 30^\circ$.

$$\sin \beta = \frac{10 \times \sin 30^\circ}{40} = .1250$$

$$\beta = 7^\circ, \text{ or } OC = \text{E. } 12^\circ \text{ S.}$$

$$\begin{aligned} \text{Also } S_r &= 10 \times \cos 30^\circ + 40 \times \cos 7^\circ \\ &= 48 \text{ m. p. s., or about 107 mi. p. h.} \end{aligned}$$

From the foregoing brief discussion, it is evident that, with an airplane of known air-speed, the successive directions toward which the machine should be headed and the total distance covered in a given time (or the time required to fly over a given course) are quickly and easily determined, providing the prevailing wind conditions are known. The great difficulty consists in finding out, at any specified time, just what these wind conditions are. This is being done very successfully at a large number of places in this country with kites carrying self-recording instruments known as meteorographs and with small rubber "pilot" balloons, whose movements through the air are followed by means of theodolites. The data thus obtained are telegraphed to the Central Office of the Weather Bureau, and bulletins are issued for the information of aviators in the Aerial Mail Service, Army and Navy Aviation Services, etc. Another method of determining wind conditions that has been used in the war and at ordnance proving grounds, is by means of so-called "Archie" bursts, which consist of puffs of smoke from a shell, the fuse being so timed that the shell bursts at any desired altitude. The movements of these smoke puffs are observed in a graduated mirror and the wind directions and velocities at the given height are readily computed. When low clouds are present several shells are sent above the clouds at stated intervals, usually half a minute apart, an airplane of known speed flies from the first smoke cloud to the last, and the aviator is thus able quite accurately to determine the current wind conditions and to set his compass course accordingly. Still another method

used in France during cloudy weather (19) consists in sending up small balloons which carry small charges of melinite so arranged that they burst successively at regular intervals. Sound telemeters record the explosions, and the position in space of the points of detonation can be thus determined. All of these methods are comparatively simple on land; they are less so at sea, yet some of them at least are by no means impossible, except in very stormy conditions. For example, a notable series of observations with pilot balloons was made by Teisserence de Bort and A. L. Rotch (20) from the deck of their steam yacht *Otaria* in 1905-1907. The ascensional rate of the balloons was known and the angular positions of the balloons were observed by means of a sextant from minute to minute. Moreover, the observations on the *Scotia* and on the *Seneca* show that kites can be used at sea with fair success. For observations by any of these methods it is advisable that the ship remain as nearly as possible in one position. Hence it would be impracticable, or at any rate difficult, to utilize trans-Atlantic steamships for this purpose. The best scheme would be to have at certain intervals along a proposed route several small ships that could make and report such observations. These ships would also be able, by means of radio communication, to act as guides for an aviator and, in case of accident, to provide a means of rescue. In order to be successful, trans-Atlantic flight, at any rate in its earlier stages, should certainly have the benefit of such assistance. Aside from the uncertainty as to wind conditions there is the added difficulty of keeping to a course, partly because of the deflective influence of the earth's rotation (21) and partly because of lack of precision in the compass itself. With clear skies sextant observations make possible the correct determination of position, but in cloudy weather the compass is the only guide unless the aviator can fly high enough to get above the clouds. Eventually difficulties of this sort will very likely be overcome by the perfection of radio apparatus of sufficient power to enable an aviator to keep in constant communication with points in both Europe and America. Even then, however, wind conditions along the course should be known as accurately as possible.

In case free-air observations are unavailable, there still remains the possibility of obtaining reports of surface conditions. Such reports could and should be furnished not only by specially detailed ships but also by those regularly plying between American and European ports. With these observations the meteorologist would be able to draw a synoptic weather map showing the surface conditions of pressure and wind that prevail at a given time, and from this map wind velocities at an altitude of 500 to 1,000 meters could be quickly determined usually with fair accuracy, from the well-known equation for gradient winds (22), viz:

$$v = \sqrt{\frac{r \frac{dp}{dn}}{\rho} + (r \omega \sin \phi)^2} \pm r \omega \sin \phi,$$

in which v = velocity in centimeters per second,

$\frac{dp}{dn}$ = difference in dynes pressure per square centimeter per centimeter horizontal distance at right angles to isobars,

r = radius of curvature of the isobar at the place of observation, in centimeters,

ρ = air density in grams per cubic centimeter,

ω = angular velocity of the earth's rotation

$$= \frac{2\pi}{86164}$$

and ϕ = the latitude.

As previously stated, wind directions at these altitudes are usually found to be very nearly parallel to the isobars. When pressure conditions are well defined and relatively stable, comparatively small error is introduced in accepting the foregoing assumptions, but when they are very irregular or when local disturbances, like thunderstorms, squalls, etc., are occurring, the principle of gradient winds must be used with caution. In general, it is more reliable over ocean than over land surfaces, because, as already pointed out, isobaric systems are larger and move more slowly over the oceans than they do over the continents.

It is not sufficient, however, for the aviator to know the *current* wind conditions. He must also be informed as to

For the purpose of illustration let us consider a type of pressure distribution that is not uncommon, and endeavor to trace out the wind conditions at an altitude of 500 to 1,000 meters along a great circle course from Newfoundland to Ireland. The time selected is the 24-hour period from Greenwich mean noon, May 29, 1906, to the same hour on May 30, 1906. Figure 3 shows the pressure distribution prevailing at the beginning of this period and figure 4 shows that prevailing at the end of the period. On these maps are also indicated the great circle courses from Newfoundland to Ireland, and from Newfoundland to Portugal via the Azores. In the study an attempt has been made to trace the changes in the pressure distribu-

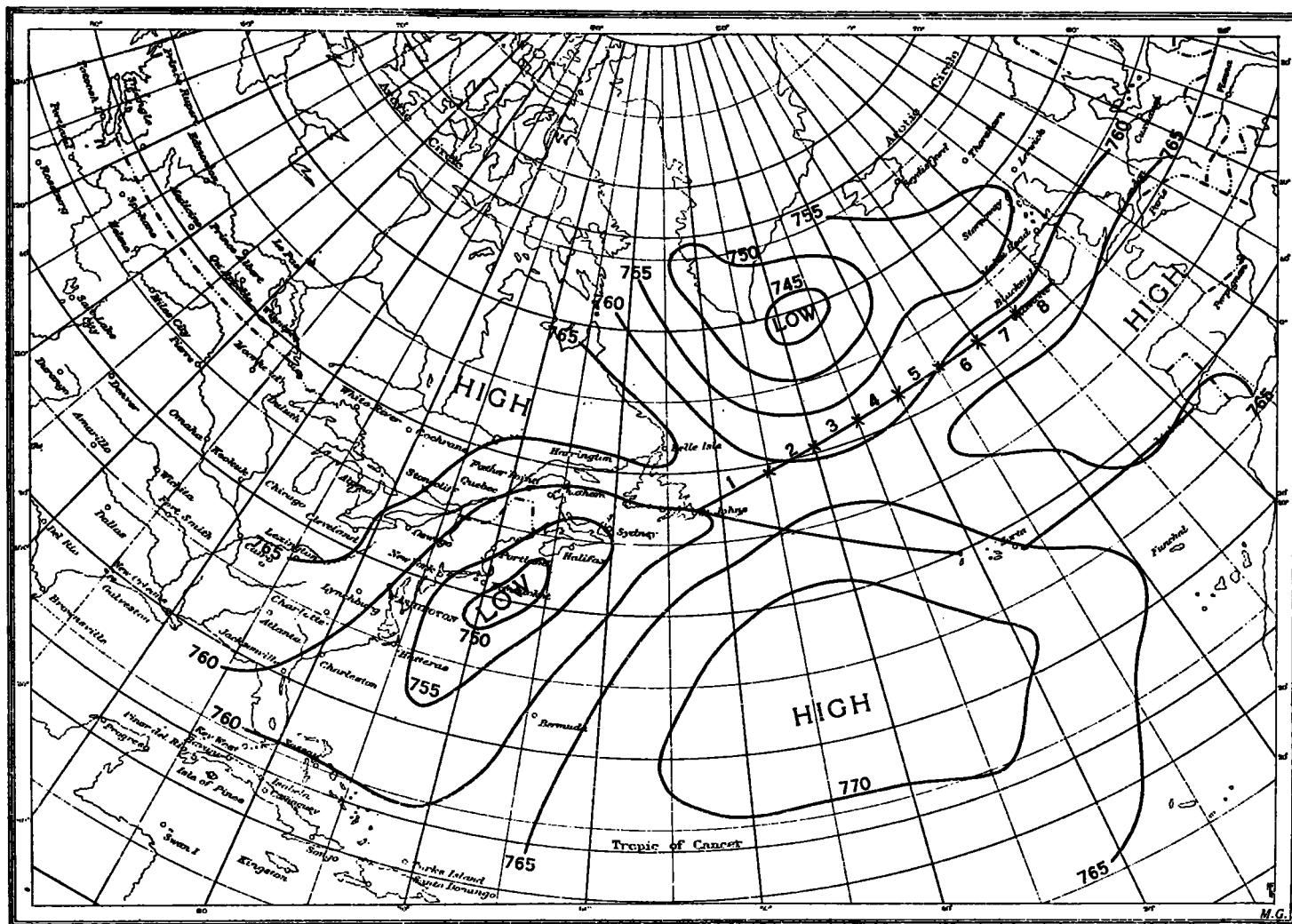


FIG. 3.—Pressure distribution, mm., over the North Atlantic at Greenwich mean noon, May 29, 1906.

the *changes* that are likely to occur during the latter part of his trip, and this may be as much as 20 to 25 hours in advance. Here again the meteorologist is assisted by the fact that isobaric systems over the ocean are relatively slow-moving. With this in mind and from a detailed study of the map before him he can construct a series of maps showing expected conditions at intervals of six hours, for example. From this series of maps he is able to determine the probable wind conditions that will prevail at successive points along the course at the times at which the aviator is expected to reach those points, these times being dependent, of course, on the air-speed of the machine and on the assistance furnished by the winds.

tion by means of intermediate maps, but these are not reproduced here. The flight is supposed to start from Newfoundland at about 2 p. m., 60th meridian time, or about six hours after the observations charted in figure 3 were made. About this much time would normally be required for the receipt and interpretation of reports.

Table 3 gives in some detail the results of this study. The course has been divided into eight sections as indicated by crosses in the figures and these sections are listed in column 1 of the table. Columns 2 and 3 give corresponding bearings and distances; columns 4 and 5 computed gradient wind directions and speed (22); column 6, the directions toward which the airplane

should be headed in order to keep to the courses indicated in column 2; column 7, resultant speeds; and column 8, the time required to cover the successive sections of the entire course, providing the airplane maintains a constant air-speed of 40 m. p. s.

TABLE 3.—Time required for flight from Newfoundland to Ireland under certain specified conditions of pressure distribution and of airplane speed and control.

Section.	Bearing.	Distances.	Gradient winds.		Airplane headed.	Resultant speed.	Time.
			Bearing.	Speed.			
		<i>Km. (miles).</i>		<i>m. p. (mi. p.)</i>		<i>m. p. (mi. p.)</i>	<i>Hrs.</i>
1.....	E. 22° N.	620 (385)	Variable.	.. (..)	E. 22° N.	40 (90)	4.3
2.....	E. 17° N.	375 (235)	E.....	8 (15)	E. 20° N.	48 (107)	2.2
3.....	E. 13° N.	355 (220)	E. 12° S.	14 (31)	E. 21° N.	52 (116)	1.9
4.....	E. 9° N.	345 (215)	E. 8° S.	16 (36)	E. 16° N.	55 (123)	1.7
5.....	E. 5° N.	340 (210)	E. 0° S.	16 (36)	E. 11° N.	55 (123)	1.7
6.....	E. 2° N.	330 (205)	E. 6° N.	16 (36)	E.....	56 (125)	1.6
7.....	E. 1° S.	330 (205)	E. 18° N.	16 (36)	E. 8° S.	55 (123)	1.7
8.....	E. 5° S.	345 (215)	E. 23° N.	14 (31)	E. 14° S.	52 (116)	1.8
Total.....		3,040 (1,890)					16.9

also for the journey by way of the Azores, although less assistance would have been furnished by the winds than along the northern route. In general, "favorable" conditions for the eastward and westward trips along the two routes may be thus summarized:

(a) Newfoundland to Ireland: High pressure at latitudes 35° to 45° N. and low pressure at latitudes 55° to 65° N. with axes extending from west to east, so that isobars run nearly parallel to the latitude.

(b) Newfoundland to Portugal via the Azores: High pressure at latitudes 30° to 40° N., central near the Bermudas with crest extending eastward, and low pressure at latitude 50° N., central about 1,000 kilometers east of Newfoundland. Under this pressure distribution isobars extend east-southeastward from Newfoundland to the Azores, thence eastward to Portugal.

(c) Ireland to Newfoundland: Reverse the conditions given under (a).

(d) Portugal to Newfoundland via the Azores: Reverse the conditions given under (b).

In all cases, the greater the pressure gradient, the greater would be the wind assistance. Occasionally

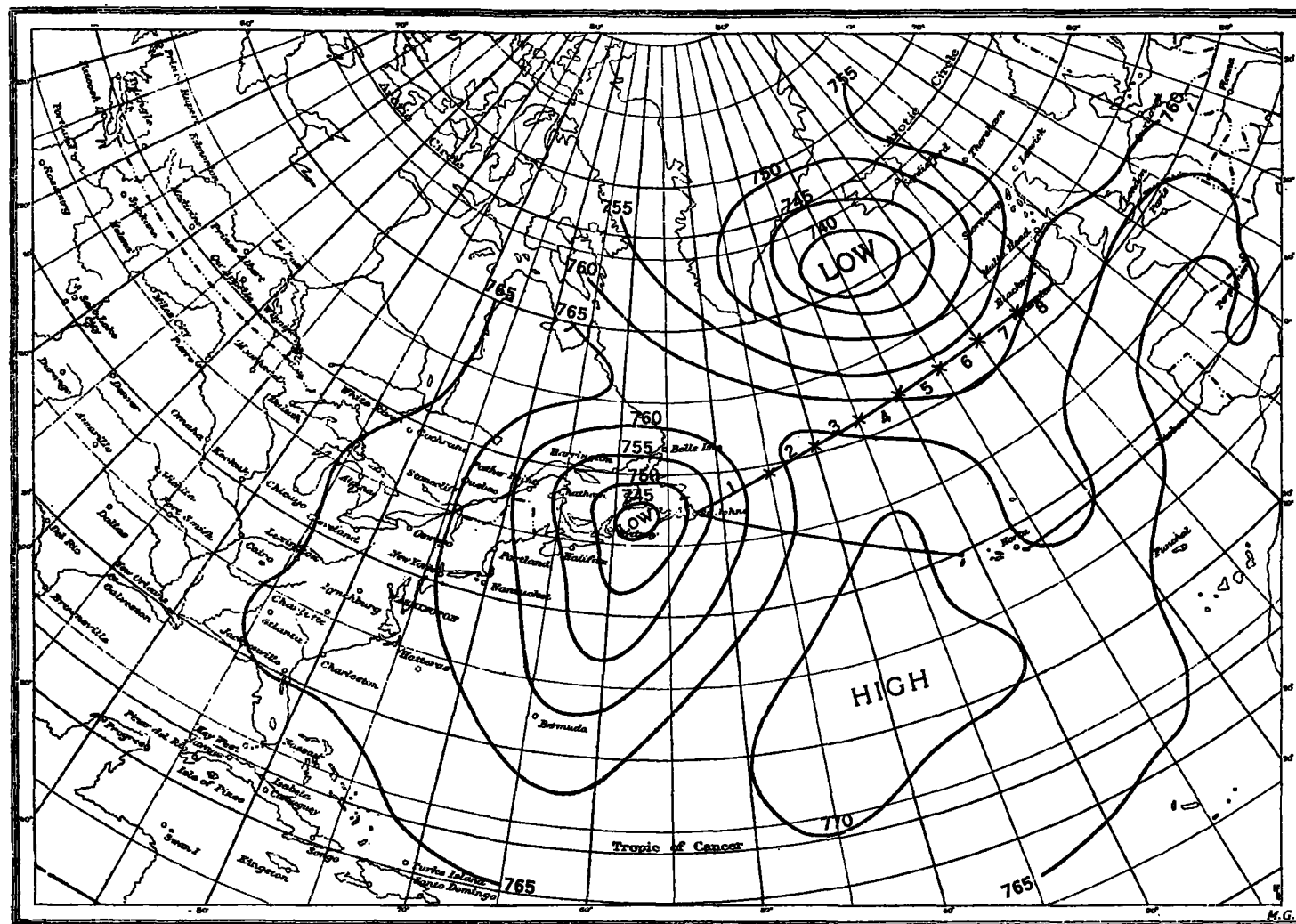


FIG. 4.—Pressure distribution, mm., over the North Atlantic at Greenwich mean noon, May 30, 1906.

Briefly, this table shows that, through the assistance given by the winds, the entire trip from Newfoundland to Ireland could have been made in about 17 hours, whereas in still air about 21 hours would have been required. This period would have been fairly favorable

there is found a high-pressure area at about latitude 45° N. with its axis extending from west to east. This condition would be favorable for both the eastward flight by the northern route and the westward flight by the southern route. An unfavorable day for any of the

journeys would be one on which conditions are the reverse of those stated under (a), (b), (c), and (d), respectively. Another type of pressure distribution unfavorable for all the journeys and one which often occurs, especially during winter, is that in which low pressure extends as a troughlike depression from north to south across both routes. Under this condition winds almost at right angles to an airplane's course would be encountered and would materially reduce the resultant speed.

In order to determine as nearly as possible, the average number of days on which favorable conditions might be expected for the four journeys during different months, all of the daily marine synoptic weather maps for the 10-year period, 1906 to 1915, inclusive, have been examined and classified. This classification has been made by Messrs. F. G. Tingley and George Paterson of the marine section of the Weather Bureau and by the writer of this paper. Each one inspected about a third of all the maps for each month, after having first compared results on a number of maps inspected independently by all three. In this way it is believed that errors of personal judgment have been reduced to a minimum. The basis of classification is as follows: An excellent day is one on which assisting winds prevail at all points along the route so that the advantage in time is about three hours or more; a good day, one on which assisting winds predominate, although head or cross winds prevail part of the way, the assistance giving a gain in time of one to three hours; fair, one on which the proportion of favoring winds is slightly greater than that of head or cross winds, so that the time required for a flight is nearly the same as if there were no winds whatever; and poor, one on which head or cross winds predominate or one on which very stormy conditions prevail. The results of the classification appear in Table 4.

TABLE 4.—Average number of days, excellent (E.), good (G.), fair (F.), and poor (P.) for trans-Atlantic flight from Newfoundland to Ireland, Newfoundland to Portugal, Ireland to Newfoundland, and Portugal to Newfoundland.

	Newfoundland to Ireland.				Newfoundland to Portugal.				Ireland to Newfoundland.				Portugal to Newfoundland.			
	E.	G.	F.	P.	E.	G.	F.	P.	E.	G.	F.	P.	E.	G.	F.	P.
January.....	8	7	4	12	5	4	8	14	0	1	2	28	3	3	4	21
February.....	3	7	4	14	2	7	4	15	0	0	0	28	1	1	2	24
March.....	3	7	4	17	3	6	6	16	1	1	1	28	0	3	3	25
April.....	2	5	8	15	1	6	7	16	0	2	3	25	0	2	6	22
May.....	5	7	4	15	3	8	8	12	0	2	2	27	1	1	3	26
June.....	2	8	6	14	1	5	5	19	0	2	2	29	0	2	5	23
July.....	6	7	8	10	2	6	11	12	1	2	5	23	1	3	8	19
August.....	5	8	7	11	3	5	7	16	0	1	1	29	0	2	4	25
September.....	3	6	6	15	3	5	8	14	1	1	1	27	1	2	4	23
October.....	3	8	5	15	1	8	7	15	0	0	0	31	0	3	3	25
November.....	1	5	6	18	0	6	5	19	0	1	1	28	0	4	3	23
December.....	2	9	5	15	2	9	6	14	0	1	0	30	0	2	1	28
Annual..	43	84	67	171	26	75	82	183	3	14	18	330	7	28	46	284

Dropping from further consideration the two classes designated fair and poor and combining the first two classes into one group as constituting all of the days that are favorable for trans-Atlantic flight, we obtain the results indicated in Table 5.

From these two tables it is at once apparent, as was to be expected, that but little assistance from winds can be gained for the westward trip along either the northern or the southern course. For the eastward trip, however, such assistance may be expected approximately one-third of the time, the percentage of favorable days being slightly greater along the northern route, due to its lying entirely within the region of the prevailing westerlies.

A detailed study of the data upon which these tables are based shows that favorable days occur on the average along the northern route 35 per cent of the time, with extremes in different years of 25 and 47 per cent; along the southern route the average is 28 per cent, and the extremes 20 and 39 per cent. When considering the monthly values we find very large variations in the same months for different years. For example, in July, 1906, there were 28 favorable days for the trip from Newfoundland to Ireland, whereas in July, 1907, there were only 4. This and several other similar cases give emphasis to the statement previously made that pressure systems over the oceans are slower moving than over the continents. Persistence of certain pressure types, with little change from day to day, is a marked characteristic of conditions over the Atlantic and should give no little comfort to an aviator who is about to undertake a flight, after having waited for days or perhaps weeks for a favorable opportunity to start.

TABLE 5.—Average number of days, monthly, seasonal and annual, favorable for trans-Atlantic flight from Newfoundland to Ireland, Newfoundland to Portugal, Ireland to Newfoundland, and Portugal to Newfoundland.

	Newfoundland to Ireland.	Newfoundland to Portugal.	Ireland to Newfoundland.	Portugal to Newfoundland.
January.....	15	9	1	6
February.....	10	9	0	2
March.....	10	9	2	3
April.....	7	7	2	2
May.....	12	11	2	2
June.....	10	6	2	2
July.....	13	8	3	4
August.....	13	8	1	2
September.....	9	8	2	3
October.....	11	9	0	3
November.....	6	6	1	4
December.....	11	11	1	2
Spring.....	29	27	6	7
Summer.....	35	22	6	8
Autumn.....	27	23	3	10
Winter.....	36	29	2	10
Annual.....	127	101	17	35

The foregoing classification has been based on the assumption that the flying level is about 500 to 1,000 meters above the surface. At greater altitudes, as already shown, the percentage frequency of westerly winds rapidly increases and, therefore, the percentage of favorable days for an eastward flight would become larger, probably increasing to 70 per cent or more at the 3-kilometer level. Conversely, the percentage of favorable days for a westward flight would decrease, although it is difficult to imagine a much smaller percentage than that indicated in Tables 4 and 5. The whole question as to the altitude most suitable for flight is still largely in the experimental stage, and the solution depends upon a thorough analysis of the various factors that enter in. For example, it is frequently found that the greatest wind assistance would be realized at an altitude of 5 or even 8 to 10 kilometers, but, on the other hand, the greater tenuity of the atmosphere at those levels would reduce the efficiency of the engine and the lower temperature and lack of oxygen would add to the discomfort of the aviator, thus making such altitudes prohibitive. Probably at the present time the most favorable height, all things considered, for trans-Atlantic flying is between 1 and 3 kilometers above the surface for the eastward trip and about 500 to 1,000 meters for the westward trip.

It is recognized, of course, that there are other meteorological factors, besides wind conditions, that enter into

the determination of the relative favorableness or unfavorableness of a day for flight, such, for example, as cloudiness, precipitation, etc. Except in so far as landing is concerned, however, wind is the one element of paramount (and, at the present time, at least, most vital) importance. Cloudiness and precipitation do not extend to very great heights over the ocean, because the high relative humidity causes condensation at a lower level here than over the land. As a rule, therefore, an aviator would be able to fly above these conditions, particularly if they covered relatively small areas. On some days stormy conditions prevail over a considerable portion of the ocean, and such days, as already stated in the paragraph preceding Table 4, have been classed as unfavorable. In this connection it is interesting, and at first thought somewhat surprising, to find that the winter season shows up so well for eastward flight as compared with the other seasons, but it should be remembered that whenever conditions are favorable during that season, they are decidedly so, because of the greater strength of the prevailing westerlies at that time of year. Many days in summer, otherwise excellent, have only light and variable winds and have therefore been classified as fair. The transition seasons, spring and autumn, have, on the one hand, more stormy days than does summer and, on the other hand, more quiet days than does winter. Hence, the percentage of favorable days is less than during the two extreme seasons.

In this paper attention has been confined for the most part to the application of meteorological conditions over the Atlantic Ocean to flight with heavier-than-air machines. The statements made apply equally well to airships. These, however, by reason of their greater capacity for fuel, and owing, moreover, to the fact that they are not dependent on motive power to sustain them, are capable of remaining in the air a relatively long time and are therefore not so vitally dependent upon favorable wind conditions as are airplanes.

CONCLUSIONS.

1. In the present stage of their development and until improvements give them a much larger cruising radius than they now have, airplanes can not safely be used for trans-Atlantic flight except under favorable conditions of wind and weather.

2. Observations of conditions over as great an area as possible, and particularly along and near any proposed course, should therefore be available at as frequent intervals as possible, these observations to include free-air as well as surface conditions.

3. With such observations at hand the meteorologist is able quickly to determine the current and probable future wind conditions along a proposed route and to advise an aviator as to the suitability of a day for a flight.

4. If a day is favorable, the meteorologist is able to indicate the successive directions toward which an airplane should be headed in order to keep to any desired course; also, to calculate the assistance that will be furnished by the winds.

5. Inspection of marine weather maps shows that at an altitude of 500 to 1,000 meters conditions are favorable for an eastward trip approximately one-third of the time, the percentage being slightly greater along the northern than along the southern route. At greater altitudes the percentage of favorable days materially increases, especially along the northern route. For the westward trip the percentage of favorable days is so small as to make trans-Atlantic flight in this direction

impracticable until the cruising radius of aircraft is increased to such an extent that they are relatively independent of wind conditions.

6. All things considered, conditions for an eastward flight are most favorable along the northern course; for a westward flight they are most favorable along the southern course; that is, the prevailing westerlies are less persistent along this course than farther north.

7. There seems to be little choice as to season, for, although the prevailing westerlies are stronger in winter than in summer, yet on the other hand, stormy conditions are more prevalent in winter, and the net result is about an equal percentage of favorable days in the two seasons. Moreover, the greater fog percentage in summer just about offsets the greater percentage of cloudiness in winter. Fog is a disadvantage chiefly because of its interference in making observations with drift indicators. The Newfoundland fogs in general are of small vertical extent and do not extend far inland. They should not, therefore, prove a hindrance to landing, if the landing field is located some distance from the coast.

8. Most important of all, there is need for a comprehensive campaign of meteorological and aerological observations over the North Atlantic (23) in order that aviators may be given data for whose accuracy the meteorologist need not hesitate to vouch, instead of information based on so small a number of observations, particularly of free air conditions, that the deductions, including some of those in this paper, are assumed and not proved, are given with caution, and are "subject to change without notice."

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THE FLIGHT OF AIRCRAFT AND THE DEFLECTIVE INFLUENCE OF THE EARTH'S ROTATION.

By CHARLES F. MARVIN, Chief of Weather Bureau.

[Paper presented before the Philosophical Society of Washington, March 29, 1919.]

It is well known that objects moving freely over the earth's surface are deflected constantly to the right by a force given by the equation

$$f = 2mv\omega \sin \phi \quad (1)$$

in which m = mass of the body, v its velocity, ω = the angular velocity of the earth's rotation, and ϕ the latitude. For each gram of matter moving at airplane speeds, say, 90 miles per hour (4,000 cm. p. s.) and at latitude 50° the force is,

$$f = 2 \times 4,000 \frac{2\pi}{86164} \sin \phi = .447 \text{ dynes.}$$

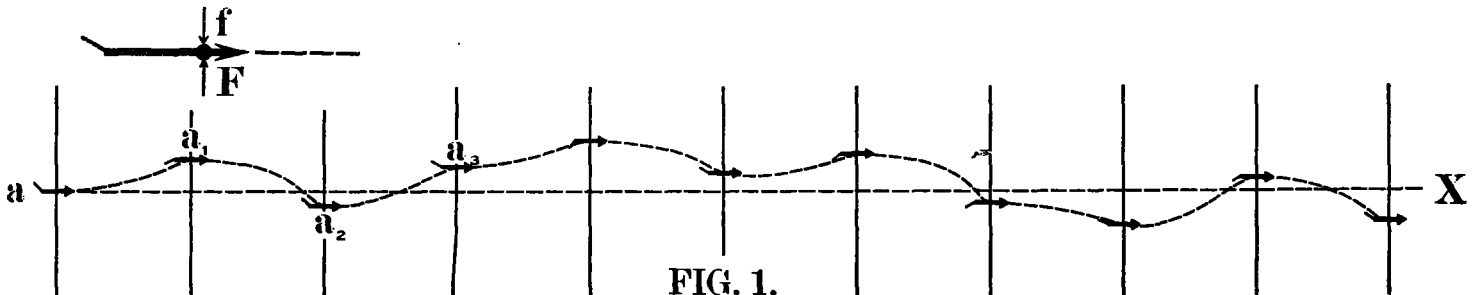


FIG. 1.

An aircraft is a body subject to such an influence even though its course be continuously controlled by a pilot and it is interesting to ascertain the quantitative effects of this small force under practical conditions of flight, as, for example, over trackless wastes where positions must be determined from the compass aided by processes of dead reckoning. For this study we can entirely disregard the influence of any winds or similar atmospheric motions, because if the conditions are known these effects can all be accounted for separately and on their own merits. Such effects on our aircraft are quite independent of the deflective influences with which alone we are now concerned. The actions we wish now to consider are such as might be observed in still air.

To ascertain how the deflective influence modifies the course of an aircraft it is necessary to make some assumptions as to how it is directed and controlled. For this purpose we assume a pilot desires to fly from a to X (fig. 1). The compass direction of X from a is supposed fully known, that is, all corrections, variations, errors, etc., are duly accounted for.

The pilot is assumed to set his craft true to course. Presently, however, close attention to the compass shows him his craft is headed a greater or less angular amount away from course. The craft is again set true

to course, only presently again to be found off course. These operations of rectifying the flight of the craft are repeated many times on a long course, with the supposed result that the craft practically follows the line aX .

The short arrows in figure 1 indicate the successive positions and alignment of the axis of the machine just after the course has been rectified. The axis of the machine is defined to be a line through the center of mass which coincides with the instantaneous path of that center when the machine is flying normally through a stationary atmosphere over a stationary earth, or over the rotating earth near the Equator.

With the enlarged arrow in figure 1 is shown the horizontal force F which is the resultant of all the horizontal

motor or air forces, resistances and reactions to which the machine is subject when in horizontal flight at a uniform velocity. The other force f represents the deflecting force due to the earth's rotation. If F and f are opposite and equal the path of the plane will be rigorously a straight line,—a great circle.

Except when he wishes to execute a relatively short turn the pilot has no control over, or knowledge of the residual force F or the direction of its action, which falls to the right or the left of the course in an entirely accidental manner. When the pilot sets his craft on a straight-away course he imagines the force F is zero, and in occasional cases this may be true. In general, however, F will have a finite value which, although relatively small, will generally be several times the value of f . The larger force will therefore dominate the flight in all cases and swerve the machine to the right or the left of the course somewhat as shown in figure 1.

In so far as the force F itself is concerned, it is believed we may properly assume that its nature is such that perturbations from course due to it are quite accidental, and in the many rectifications which must be made in any case the influences of F will tend to be automatically eliminated or averaged out. That is, ΣF for even a comparatively small number of cases continually tends to be zero. Accordingly, in a long flight